GEOTHERMAL RESOURCES AND DEVELOPMENT IN CHINA

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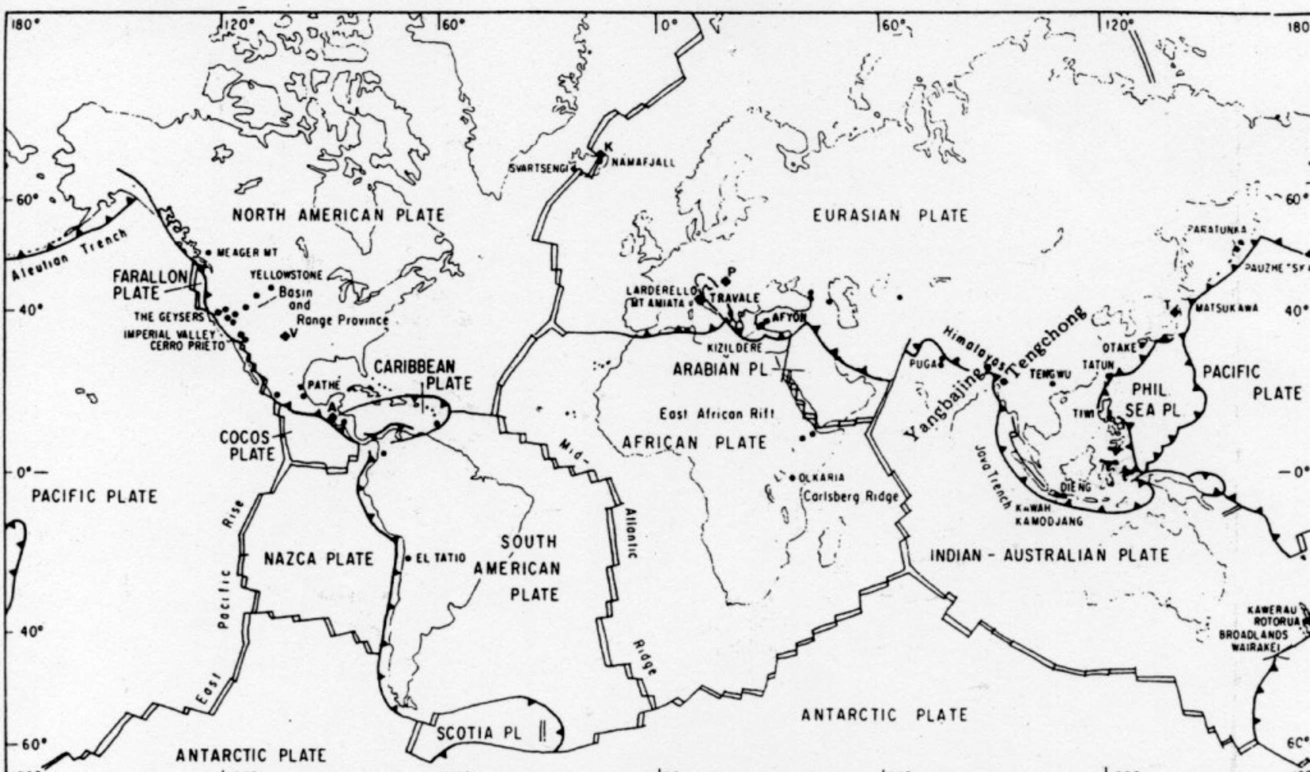
ABSTRACT

China is rich in geothermal resources and has a long history of utilization. At present, a geothermal power plant with installed capacity of 25.18 MW has been set up in Yangbajing Geothermal Field, which supplies about 41% (more than 60% in the winter time) of the total electricity to the Lhasa city, the capital of Xizang (Tibet). In addition to power generation, geothermal resources are widely used for space heating, industry processing, agriculture, bathing and spas. In 1990, the total flow rate of thermal water for direct use amounts to 9534 kg / s, which provides the thermal power of 2143 MW and a thermal energy of 5527 GWh equivalent. These figures show that China nowadays is the second largest user of non-electric purposes of geothermal energy in the world.

Key words: Geothermal background; Geothermal Resources; High temperature; Low-medium temperature; Development and Utilization; China

INTRODUCTION

China is rich in geothermal resources and has a long history of using hot springs for agriculture, bathing and therapeutic purpose. Since early 1970's, extensive exploration and development of geothermal resources have been launched and quite good results were obtained. At present, a geothermal power plant with installed capacity of 25.18 MW is installed in Yangbajing Geothermal Field, which supplies about 41% (more than 60% in the winter time) electricity to Lhasa city, the capital of Xizang (Tibet) Autonomous Region. Another two geothermal power plants (Langjiu and Naqu) have been installed in Tibet to meet the growing needs for electricity and to help solve the energy-shortage problems in this remote area. Except for power generation, geothermal resources are widely used for space heating, industry processing, agriculture, bathing and spas. In 1990, the total flow rate of thermal water for direct use amounts to 9534 kg / s, which



Spreading ridge; Subduction/ Trench; Transform fault; Plate interior undergoing active extension compressional or strike-slip faulting.

FIG 1: Global distribution of major geothermal systems related to plate tectonics (Rybach, 1981, with supplementary data from China) provides the thermal power of 2143 MW and thermal energy of 5527 GWh equivalent. These figures showed that China nowadays is the second largest user of non-electric geothermal energy in the world (Ren et al., 1990; 1995; Freeston, 1990).

TECTONIC SETTINGS AND GEOTHERMAL BACKGROUND

Being located in the southeastern corner of Eurasian plate, the continental area of China is both influenced by the Pacific Plate from the east and the Indian-Australian Plate from the south (Fig. 1). As a result, two geothermal belts are formed. One is the so-called "Himalayan Geothermal Belt" in SW China, which is the eastern extension of the worldwide Mediterranean Geothermal Belt and another is the so-called "Circum-Pacific Fire Ring" or "Circum Pacific Geothermal Belt" in the southeast. The famous high-temperature geothermal fields such as Kizildere from Turkey and Puga from India are located in the former belt and Paratunka from Russia, Matsukawa and Otake from Japan plus Tiwi from Philippine are situated in the latter Belt. In China, Yangbajing Geothermal Field in Tibet and Tengchong volcanic area in Yunnan Province belong to Mediterranean-Himalayan Belt, whereas Datun (Tatun) geothermal area in Taiwan occurred in Circum-Pacific Belt (Fig. 1)

Geothermal background for the above-mentioned two geothermal belts turns out quite high. Heat flow studies (Wang and Huang, 1990) indicate that average heat flow in S. Tibet appears around 80-100 mW / m^2 with the highest up to 364 mW / m^2 (Shen et al., 1992), and for Tengchong volcanic area, >80 mW / m^2 (Wang et al., 1990). Taiwan is gener characterized by high heat flow (>80 mW / m^2) and in high-temperature geothermal areas, heat flow appears> mW / m^2 (Lee and Cheng, 1994).

Geothermal background of China is closely correlated to tectonics. Generally, the young and more active the regi the higher the geothermal background, and vice-versa. instance, Tibet, Tengchong and Taiwan are active tecto units of Cenozoic age, the geothermal background is high. the contrary, the old stable terrains such as Yangtze f block of Proterozoic age and Archean Sino-Korean f block are characterized by low heat flow and low geother gradient. Relatively high heat flow (63 mW / m^2) geothermal gradient (35°C / km) are observed in North Ch Basin because by the end of Mesozoic and extending to e Cenozoic era, North China Basin had undergone a rift de opment stage. Spatially, geothermal background is high in East and South, but low in the West and North as is dem strated by Fig. 2. The reason is that since Mesozoic era, continent of China is strongly influenced by the Pacific P from the East and the Indian- Australian Plate from South (Wang, 1993; Wang et al. 1995).

HIGH TEMPERATURE GEOTHERMAL RESOURCE

High temperature geothermal resources in China are conc trated in recent volcanic and tectonically active areas. southern Tibet, there are more than 600 hydrothermal m festations including high temperature geysers, hydrother explosions, steaming grounds, fumaroles, boiling springs among which 345 have been identified and investigated by

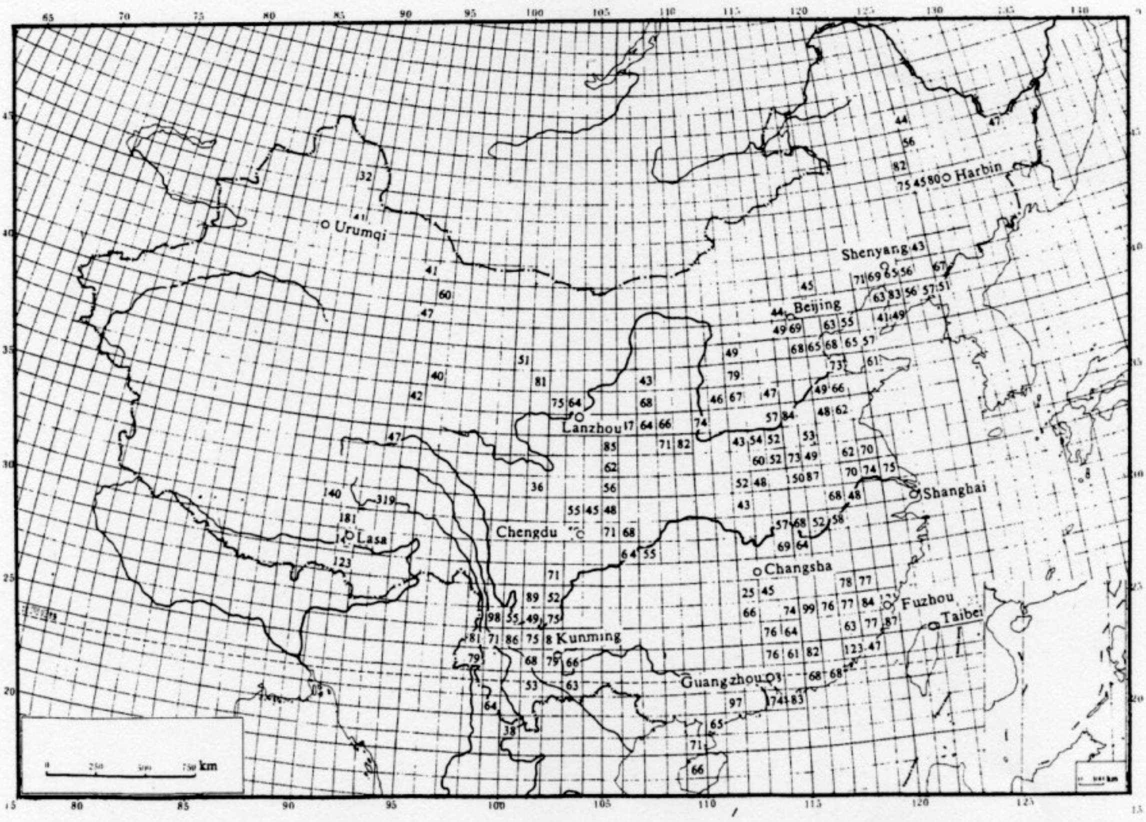


FIG 2: Heat flow distribution in 1° × 1° grids with average value in each grid for continental area of China

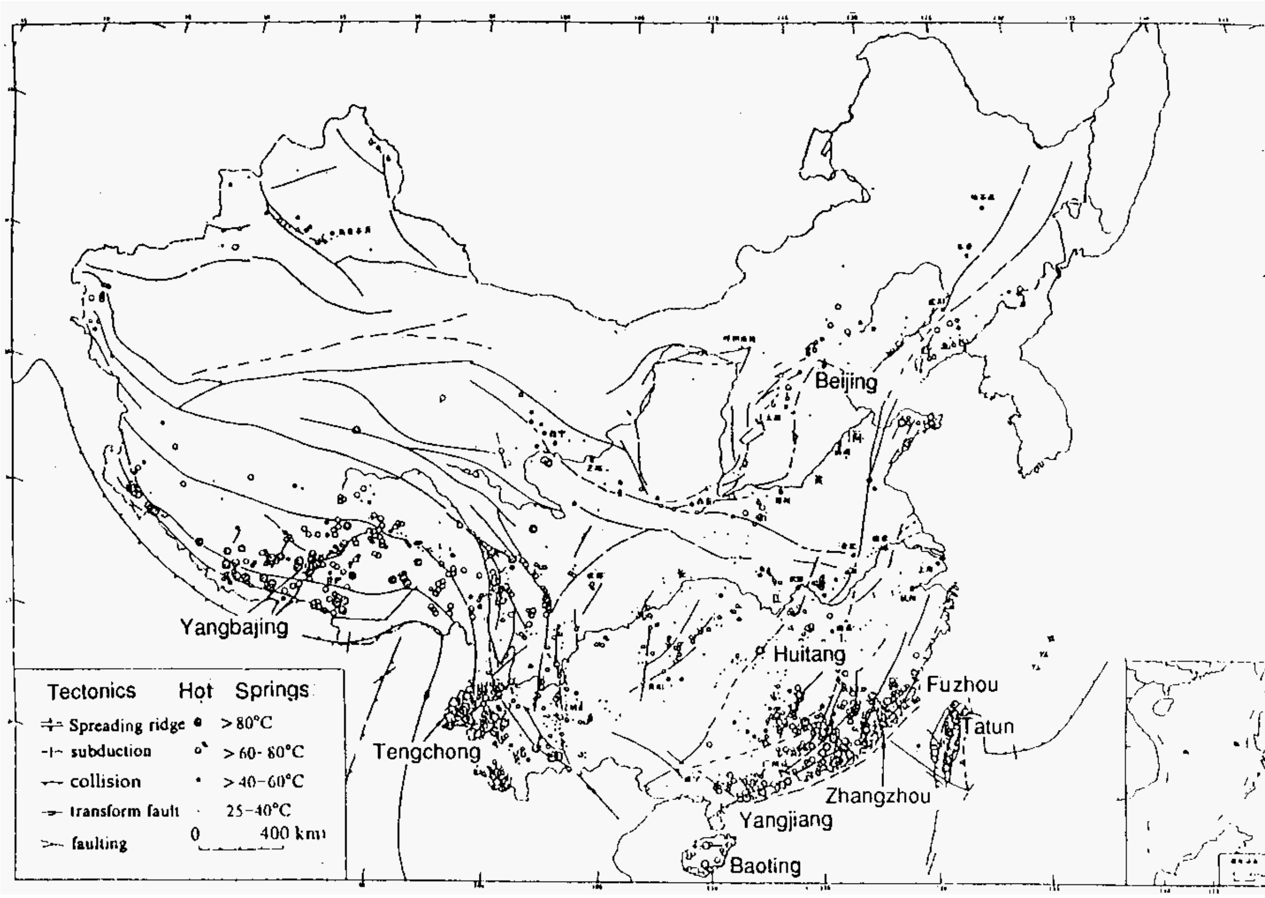


FIG 3: Convective geothermal systems of in China

Scientific Expedition Team under Commission for Integrated Survey of Natural Resources, Academia Sinica in late 1970's (Tong et al., 1981) (Fig.3). Results indicate that most of thermal water in S. Tibet are of $Cl^{-}-HCO_3^{-}-Na^{+}$ type with enhanced contents of Li, Rb. Cs and B. The total dissolved solid appear between 1–3 g / l and the water is of meteoric origin as evidenced by isotope and geochemical studies. The estimated reservoir temperature varies from 170 to 270°C and the total natural heat discharge at the Earth's surface amounts to 4,900 × 10^{13} J / a (Shen and Chen, 1994).

A total number of 58 hydrothermal areas were identified in Tengchong among which the Rehai (Hot Sea) geothermal system is the most promising one. Investigation revealed that the reservoir temperature in this system may reach 230–240°C. The heat source might be a cooling magma body which intruded into a shallow depth of about 5–7 km and created the circular area of surface manifestation. The input of magmatic heat at depth may have set the ground–water into motion in this geothermal system. However, the ground water is meteoric in origin as indicated by isotope (Tong et al., 1989).

About 80 hot springs and fumarolic areas have been reported from Taiwan. Datun (Tatun) and Tuchang are the two explored geothermal fields. The former lies in a volcanic region and the latter, in a slate formation. The deep reservoir of Datun Field contains acid sulphate chloride water with pH around 2 and temperature up to 293°C. The Tuchang Field produces $HCO_3^{-}-Na^{+}$ water having pH around 8.5 and temperature up to 173°C. The estimated potential for power generation in Datun is about 100 MW (Chen, 1989).

LOW–MEDIUM TEMPERATURE GEOTHERMAL RESOURCES

There are two types of low–medium temperature geothermal resources in China. One is thermal water from the low–medium temperature geothermal systems of convective type, not related to young magma bodies but heated by normal to relatively high regional heat flow, such as the Zhangzhou and Fuzhou geothermal systems in SE China. Another is the thermal fluid connected with the low–medium temperature geothermal systems of conductive type in large–scale sedimentary basins, such as North China Basin, Sichuan Basin and Talimu (Tarim) Basin (Wang et al., 1992).

It can be seen from Fig. 3 that the geothermal resources of first type are concentrated in the following areas:

1) Coastal area of SE China including Fujian, Guangdong, Eastern Jiangxi and Southern Hunnan Provinces. There occurred more than 600 hot springs mostly with temperature of 40–80°C, some having temperature 80–95°C. Several systems such as Zhangzhou. Fuzhou in Fujian Province; Dengwu (Tengwu), Yangjaing in Guangdong; Baoting in Hainan and Huitang in Hunan Province have been explored during the past 20 years;

2) E. Shangdong, E. Liaoning Peninsula to the East of Beijing along Tancheng–Lujiang deep–fault zone. There exist about 70 hot springs with temperature of 40–70°C. Higher temperature (80–90°C) are observed in several springs;

3) Fen–Wei graben area to the West of Beijing. The distribution of hot springs is "S" shaped reflecting the graben configuration. Hot springs from the northern and southern parts of the graben are of higher temperature (60–80°C) whereas those

from the middle part are of lower temperature (40–60°C). It might result from the different circulation at depth of hot spring water;

4) W. Sichuan–N. Yunnan area to the NE of Tengchong along " South–North" tectonic (or seismic) zone. A total number of 270 hot springs are recorded far this area. The temperature of springs is quite low (40–50°C), only a few appear to he more than 80°C.

Geothermal background for these areas varies from 40 to 75 mW / m^2 (Fig. 2). It is obvious that there is no particular heat source (magma body) underneath these systems. The temperature of thermal water in these systems depends mainly upon the circulation at depth of the water. The deeper the water. the higher its temperature will he and vice–versa. For instance, the circulating depth of thermal water in Zhangzhou geothermal system is quite large (3.5–4.0 km), so the highest temperature (121.5°C at a depth of 90 m) is observed along the coastal area of SE China (Wang et al., 1993).

Isotope and geochemical studies exhibit thermal water in these systems originated from meteoric water. Along the coastal area, thermal water in some systems was revealed to he mixed up with sea water. As a result, the TDS and Cl^- content are increased (Pang et al., 1993). The reservoir temperature for this type of geothermal systems range from 40 to 150°C calculated by using different geothermometers. For example, reservoir temperature for Zhangzhau and Yangjiang systems are of 140°C; for Dengwu— 135°C; for Baoting— 120°C (Wang et al., 1994).

Geothermal resources in low–medium temperature geother mal systems of conductive type mainly occur in large–scale sedimentary basins. In China, there exist a number of such basins among which 9 basins have an area more than 100,000 km'. Namely they are: Songliao, North China, Eerduos (Ordos). Erlian, lianghan, Sichuan, Talimu (Tarim). Chaidamu and Zhungeer Basin. A total area of approximate 3.5 million square kilometres is reached if the sedimentary basins with an area more than 200 km^2 are taken into consideration. It accounts for 36% total area of China continent. In Fig. 4, 21 major sedimentary basins of Meso–Cenozoic age are presented (Chen et al., 1994).

Investigation and exploration demonstrated that sedimentary basins located in the eastern and central parts of China are most promising areas for development of low–medium temperature geothermal resources. Basins from western China such as Talimu (Tarim), Chaidamu and Zhungeer are less promising because the water quality is not so good and the salinity seems to be too high (up to 30 g / l). In addition, W. China is less populated and, there is no user for the vast desert areas except for a few big cities and towns. Recently, an evaluation on the potential of thermal water resources for 9 basins from eastern and central China has been attempted (Deng et al., 1994).

It must be noted that the potential of geothermal resources in these basins is quite good and the recoverable thermal water resources amount to 1.854 billion tons of standard coal equivalent. The recoverable resources in North China Basin and N. Jiangsu Basin takes up 73% of the total and thus, these two basins are the most promising areas for the development of low–medium temperature geothermal resources in China. Although the extent of Feng–Wei Basin And Lei–Qiong Basin is not so large, these two basins are still quite promising for development because the water quality is good and the flow rate is large enough for exploitation. Except for Chuxiong basin, the water quality for other Mesozoic basins such as Sichuan. Eerduos (Ordos) and Songliao appears not *so* good. Therefore. these basins are not very promising for geothermal development.

DEVELOPMENT AND UTILIZATION

As stated before, China has a long history (over 2000 years) of utilization of geothermal resources. Early people used hot springs for irrigation and clothes–washing. During Han Dynasty (206 BC to 220 AD), salt was extracted from thermal water in Zigong area of Sichuan Province. In the Ming Dynasty (1368–1644 AD), Lishirheng, a famous medical doctor at that time, used hot spring water for disease treatments. He persuaded people: "If you got ill, go to hat spring area and take a bath". As a result, numerous bathing houses and spas were spread over hot spring areas throughout the country. In Xiaotangshan (a little warm hill) hot spring area (25 km to the NW of Beijing), two thermal water pools were sunk in 1666, the 5th year of Emperor Kangxi of the Qing Dynasty. And a bathing tank was constructed for the famous Empress Dowager Cixi. In Huaqingchi hot spring area near Xi'an city, the ancient capital of Tang Dynasty, a quite fancy bathing house was built up for the Imperial Concubine Yang. However, all these uses were mainly for ('health" and/or "recreation" purpose, rather than for energy.

Since the early 1970's, recognizing the importance of geothermal energy as an alternative new and renewable energy source, geothermal resources have been started to be used for energy purpose. An experimental geothermal power Station was set up in Dengwu (Tengwu on Fig. I), Fengshun County. Guangdong Province in 1970 and followed by Wentang and Huailai in 1971. Huitang in 1975 and finally, Yingkou in 1977 (Fig. 5).

It is clear that the capacity of all the experimental geothermal power stations is too small and the efficiency is too low due to the low temperature of the thermal water for power generation. At present, only Dengwu and Huitang are still in operation (part time), and the remaining three were shut down several years ago. In 1977, *a* geothermal power plant was set up in Yangbajing Geothermal Field using thermal water with 5–20% vapour at a temperature up to 202°C. By the end of 1993. the installed capacity reached 25.18 MW (Ren et al., 1994). As high temperature geothermal resources are concentrated in Tibet, Tengchong volcanic area and Taiwan. geothermal power generation is mainly conducted in these areas.

Taiwan started to investigate the possibility of using geothermal energy for power generation in 1960's. An experimental power plant was set up at Qingshui geothermal area with capacity of 3MW in 1981 (Chen et al., 1989).

It must be pointed out that although the total amount of geothermal power production at present and in the near future seems to be too small. it may still make great sense in solving the energy shortage problem of the remote areas in Tibet, West Yunnan etc. In this context, we are going to put continuous effort with the hope to contribute more electricity from geothermal energy.

As mentioned at the very beginning in this paper, China is the second largest user of non-electric geothermal energy and "is showing out as a prospective leader in direct uses" (Freeston, 1990). There are about 49 projects using thermal water for industrial processing such as dyeing. drying fruits and vegetables. paper and hide processing, air conditioning and preheating boiler feed water ete. with a net energy consumption of 171 GWh.

Space heating is mainly applied in North China where severe

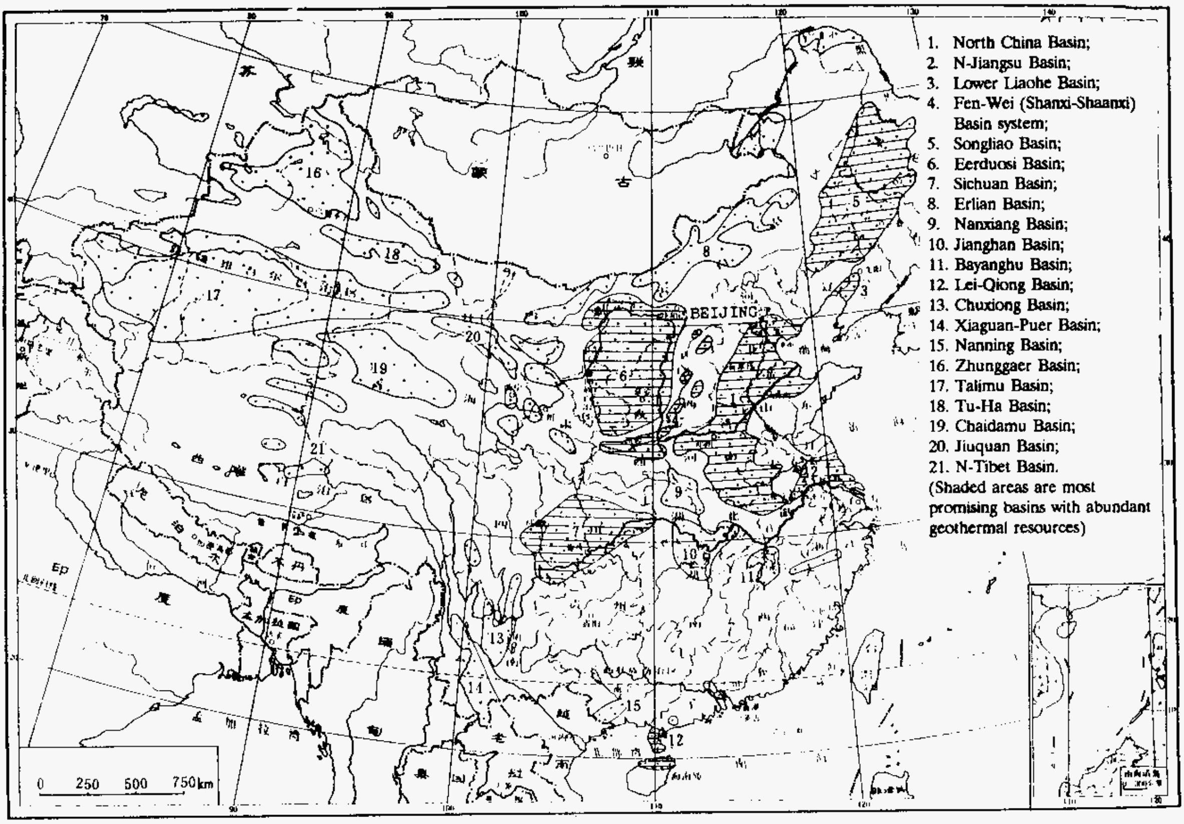


FIG 4: Major Meso–Cenozoic sedimentary basins in China

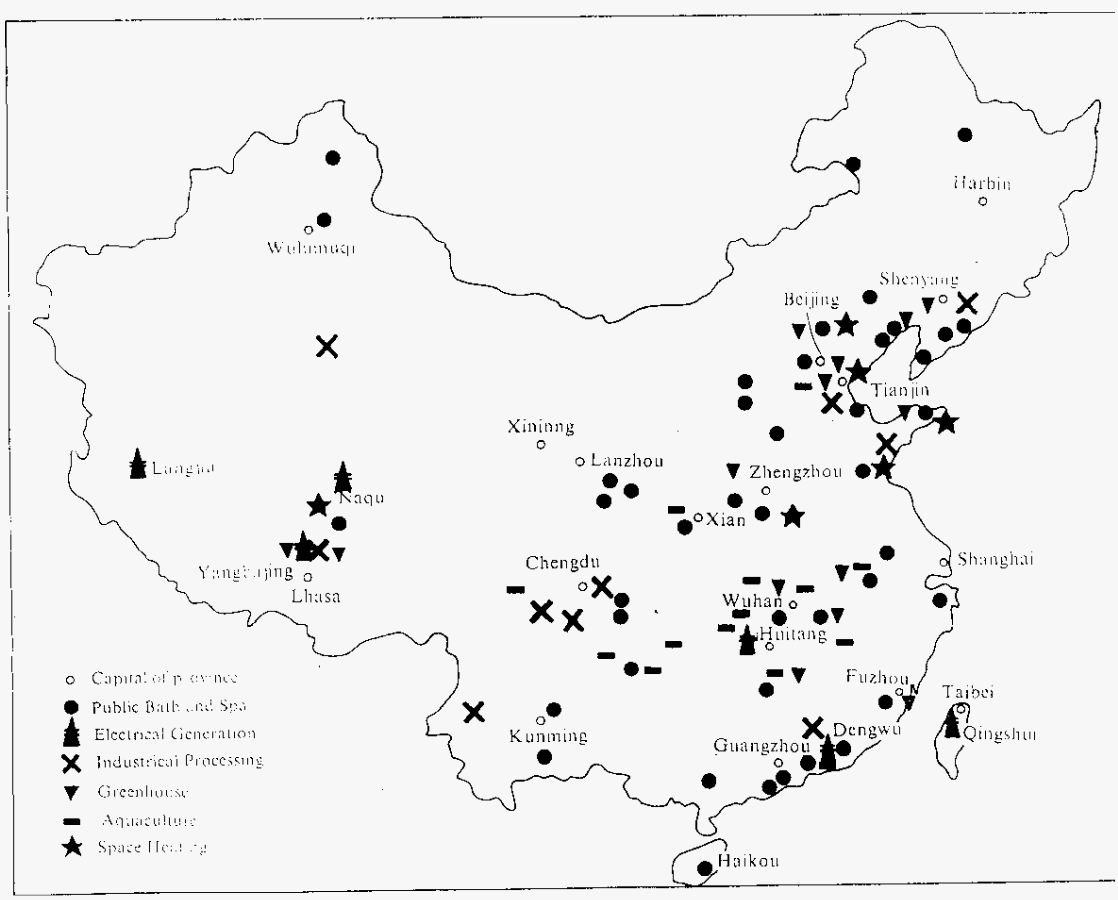


FIG 5: Geothermal utilization sites in China (Modified from Ren and Tang, 1989)

cold winter exists. With an energy utilization of 334 GWh, the heating area totals 1,313,800 m^2. Geothermal space heating systems in Tianjin are concentrated in Tanggu, Hangu and Dagan districts. About *50* wells provide a maximum flow **of** 300 t / h of up lo 97°C water to heat an area of 805,000 m^2. This is the largest single spacing heating project in China so far. The space heating projects in Beijing are spread over **a** large **area of** the city, but there is no central heating systems, usually one well for one unit only. The largest one is at Xiaotangshan sanatorium. where 4 wells provide 137 t / h of 50°C water to heat a total area of4.000 m^2.

Greenhouses also feature as major users of thermal water in China. In 1990. China has greenhouse area **of** 1,159,156 m^2 in 17 provinces and/ **or** autonomous regions, of which 258, 129 m^2 are in Hebei Province, amounting to 22.3% of the total. Two standard designs of greenhouse are used to produce fresh vegetables. the main crops being cucumbers, tomatoes and lettuce. The farmers in Xiaotangshan County have built up 43,290 m^2 greenhouses and supply the grand hotels and fancy restaurants in Beijing with ten different kinds of special vegetables. In 1984, when President Reagan of the United States visited China, instead of getting vegetables by air from California, a variety of fresh vegetables from Xiaotangshan geothermal greenhouse were put on the table **far** the farewell banquet at Great Wall (Beijing Sheraton) Hotel, which surprised **and** was enjoyed by the guests and host. Fish-farming by thermal water appears to be another fast growing application in China. At present, **a** total area of 1.6 million square meters offish ponds is reported in 17 provinces and cities. The products include African carp, eels, shrimps, turtles. snails etc. In Fujian Province, **a** large number of eels have been raised in geothermal fish ponds and the products **are** partly exported to Japan.

Currently, there are 594 baths, 23 swimming pools and 179 sanatoriums. with many **more** local pools at hot spring sites. The swimming pools and baths using thermal water for athletic training have developed rapidly in recent years. The famous training centre for female volleyball team using thermal water is located in Zhangzhou City, Fujian Province. It is interesting to note that the 4 provinces making major use of thermal water for non-electrical processes are Hebei, 24% ***of*** the country total; Tianjin. 15%; Shandong, 12% and Tibet, 10% (Ren et al., 1990; Freeston, 1990).

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